POLICY AND PREPARATION FOR

THE AIR FORCE CIVIL ENGINEERING SPACE MISSION

THESIS

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THESIS

Presented to the Faculty of the School of Systems and
Logistics of the Air Force Institute of Technology
Air University
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Master of Science in Engineering Management

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Preface

The purpose of this research was to review the work being done within Air Force Civil Engineering to prepare for its role in space. Policy was reviewed to determine what is the role for Civil Engineering in space and how Civil Engineering is preparing to meet the challenge of future space maintenance responsibilities. The research was conducted to help determine what items in the area of training, technology and maintenance procedures Civil Engineering must develop in order to extend their mission of providing real property assets to support the Air Force mission to the extraterrestrial domain.

I would like to thank several people for their help and patience throughout this research. First, Lt Col James R. Holt, my advisor, for his continued assistance and guidance. Next, I would like to thank the members of Air Force Space Command Headquarters who helped with the research and interviews to make this thesis possible. Also, I would like to thank my wife, Vicki, for her ever-present encouragement and patience in this endeavor. Finally, I wish to give the glory to God without who's strength I could not have completed this task.

Gary Bruce Arnold

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Notation

ACCESS	-	Assembly Concept for Construction of Erectable Space Structures
AFCE	-	Air Force Civil Engineering
AFIT	-	Air Force Institute of Technology
AFOSR	-	Air Force Office of Scientific Research
AFSTC	-	Air Force Space Technology Center
AFWL	-	Air Force Weapons Laboratory
CE	-	Civil Engineering, Civil Engineer
DoD	-	Department of Defense
E&S	-	Engineering and Services
EASE	-	Experimental Assembly of Structures in EVA
ESA	-	European Space Agency
ESSLG	-	Engineering and Services Space Liaison Group
EVA	-	Extra-Vehicular Activity
HQ AFSPACECOM	-	Headquarters Air Force Space Command
LSS	-	Large Space Structures
MMU	-	Manned Maneuvering Unit
MTFF	-	Man-Tended Free Flyer
NMERI/RTAG	-	New Mexico Engineering Research Institute/Readiness Technical Analysis Group
OMV	-	Orbital Maneuvering Vehicle
ORU	-	Orbital Replacement Unit
Solar Max	-	Solar Maximum Mission satellite
SOS	-	Space Operations Simulator
STS	-	Space Transportation System, space shuttle
USA-CERL	-	U. S. Army Construction Engineering Research Laboratory

Abstract

This research examines past and present work toward space operations for Air Force Civil Engineering. The objective is to determine work that is necessary for Civil Engineering to extend its mission into space. Topics discussed are policy, training, technology and maintenance concepts. Analysis of this information leads to projected actions Civil Engineering must take in the immediate and long range future.

We have learned many things from space research and development. Technological advancements from space research have improved our lifestyles. Training techniques developed to simulate space have been successful in duplicating the actual environment. Procedures for corrective and preventive maintenance of space systems was demonstrated on Skylab. The Solar Max mission proved that on-orbit retrieval is possible.

Civil Engineering has a policy statement for space support and is developing doctrine for space operations. Civil Engineering must develop doctrine and plans to implement space policy. Civil Engineering must develop a blueprint on how it will operationalize the concepts for space into actual procedures. An Office of Primary Responsibility should be organized for managing requirements, planning and developing the issues facing Air Force Civil Engineering. This office would also coordinate technical information about space.

New maintenance concepts and procedures are being developed and tested. The prominent maintenance methods are variations of aircraft

maintenance Present space assets are systems which do not use facilities maintenance. Civil Engineering must determine procedures for space facilities maintenance. On-orbit servicing is a logical extension for a future maintenance. The increasing capabilities of artificial intelligence . have a dramatic effect on maintenance procedures in space.

Other projections include power reliability for ground support facilities, training requirements for power technicians, improvements to training, proposed maintenance using on-orbit retrieval, terrestrial basing and man in space.

POLICY AND PREPARATION FOR

THE AIR FORCE CIVIL ENGINEERING SPACE MISSION

I. Introduction

The Situation

Maj Gen George Ellis (USAF Ret), during his tenure as Director of Engineering and Services, established a space policy for Civil Engineering. Civil Engineering will:

> Provide support to the ground components of military space capabilities; Provide the required standards of facility reliability and performance; and Develop capabilities to construct, operate, maintain and repair facilities in space. (E&S, HQ USAF, undated)

This space policy is an extension of the Air Force Civil Engineering (AFCE) mission "to provide the necessary assets and skilled personnel to prepare and sustain global installations as stationary platforms for the projection of aerospace power in peace and war" (Dept of the Air Force, 1982b:9) into the space domain.

There will be stationary platforms (or facilities) in space and someone will have to maintain those facilities. Civil Engineering (CE) must be able to perform its role in space. This research examines how CE will support our space policies and prepare for its role in space.

Background

Air Force Civil Engineering is responsible for the construction, maintenance, and repair of the facilities, utilities, pavements, and grounds at air bases worldwide. This includes the ground support of space-vehicle launch facilities and satellite tracking stations. Vandenberg AFB is an example of a space support location with launch facilities. Also, there are many facilities such as radar and satellite tracking facilities which require Civil Engineering maintenance and repair actions. Thus, CE is involved in the space support business already.

Presently, we do not have stationary platforms in space requiring constant manning or needing facility maintenance. But in the future, CE will have to construct, maintain, and repair such space facilities. It will be CE's responsibility to support the needs of unique structures and maintenance requirements.

CE is not fully prepared to operate routinely in space today. The traditional CE craftsmen are carpenters, plumbers, electricians, and pavements technicians. These construction skills do not use advanced technology. Materials for space construction may involve metals capable to withstand high changes in temperature and pressure. CE does not normally work with such materials. Few companies have dealt with equipment in space, space construction, and maintenance of space facilities and systems. Space requires new technologies which most engineers and technicians have not dealt with before. This is even more true for Air Force Civil Engineers.

Purpose of the Research

Civil Engineering faces a unique and challenging opportunity to prepare for future space operations. CE must begin preparing now to support space facilities requirements and responsibilities. This preparation should include developing doctrine, policy and guidance;

providing training and education of space systems; increasing the working knowledge of the technical requirements; and developing maintenance and repair procedures. CE must determine the goals which must be set and what actions must be taken to meet those goals. The specific areas which will be looked at in this thesis are: the Civil Engineering policy for space, training needs for CE's role in space, the technology involved in space facilities, and space facilities maintenance concepts. The following questions will provide a guide to determine CE's efforts toward the space program.

1. What is Civil Engineering's policy toward space?
2. What technology is available or being developed for long term space facilities?
3. What are the requirements for maintenance of space facilities or space systems?
4. What is/will be the Civil Engineering role in maintenance of space facilities?
5. How can Civil Engineering prepare for a new mission in space? What is being done to prepare for a new mission in space?

Past and present work will be reviewed to identify any deficiencies and project immediate and long-term needs.

Method of Research

This research combines two methodologies: a literature search and interviews with experts. A literature review included related areas such as policy, training, technology, construction, maintenance and repair/servicing. The information from the literature search provides a background for space facilities maintenance and glimpses of future requirements. Periodicals provided recent viewpoints on policy and the use of space. Technical journals provided information on the challenges in technology and in space maintenance. The literature search consolidates relative past research into a readily available source of information.

The interviews provide up-to-date information about space-related activities. The experts provided the most recent information in the field from open-ended questions. A copy of the interview questions is provided in the Appendix. The researcher will evaluate the information from past and present work, project short falls in the work, and forecast future needs.

II. Policy

Introduction

The first step to understanding and developing the role of Civil Engineering for space is to know the policy for CE in space. This chapter reviews current policy toward space. Conclusions will be made concerning space policy for CE.

U. S. Policy

Space is a medium of operation and our reliance on space has increased over the past 30 years (Carlucci, 1988:2-3). This reliance will continue. Assets in space provide surveillance, navigation, communication and tactical warning and assessment (Koser, 1986:6-9). The Air Force and civilian industry have on-going efforts researching manned and unmanned repair aspects of space operations (Wile, 1988:32).

The National Aeronautics and Space Administration (NASA) is the lead non-military government agency for space. NASA was responsible for the past achievements in the space race and is working on a space platform. This platform may or may not be available for use by the military. NASA's space station must be viewed "as a facility offering large-scale utilities and services to many users on a time share basis, similar to any multipurpose ground facility [Fuchs, 1984:105]."

However, questions remain about who will logistically support space assets (Bowman, 1986:13). Dale Myers, NASA's Deputy Administrator, suggested that the Pentagon will need to develop its own space station (Ulsamer, 1987:83). Mr Myers' point identifies the need for the military space missions to follow a separate path than NASA.

Department of Defense Policy

The United States Space Command was activated on September 23, 1985 and plays an intricate part in our national security (Herres, 1986:2). As a Unified Command, the U. S. Space Command combines the knowledge and capability from the four services. Each of the services has a part in the development of space technology and operations.

Official military space policy occurred on February 4 1987, when Secretary of Defense Caspar Weinberger signed a space policy statement for the Department of Defense (DoD).

> The primary DoD goal in space is to provide operational capabilities to ensure the U.S. can meet national security objectives. Contributory goals include a strong and forward-looking national space technology base, a healthy space industry to support national security and support to our Allies.
>
> DoD space efforts will contribute to the national security objectives by: 1) deterrence, or if necessary, defense against enemy attack; 2) assuring that forces of hostile nations cannot prevent our own use of space; and 3) enhancing operations of U.S. and Allied forces by space systems. DoD space policy supports and amplifies U.S. national space policy. Space is recognized as being a medium within which the conduct of military operations in support of our national security can take place, just as on land, at sea, and in the atmosphere, and similarly from which military space functions of space support, force enhancement, space control and force application can be performed. (DoD, 1987:1-2)

On 5 January 1988, DoD policy was supported when the President of the United States approved a revised space policy. This policy provides the national goals of our space program.

> The overall goals of United States space activities are: (1) to strengthen the security of the United States; (2) to obtain scientific, technological, and economic benefits for the general population and to improve the quality of life on Earth through space-related activities; (3) to encourage continuing United States private-sector investment in space and related activities; (4) to promote international cooperative activities taking into account United States national security, foreign policy, scientific, and economic interests;

(5) to cooperate with other nations in maintaining the freedom of space for all activities that enhance the security and welfare of mankind; and, as a long-range goal, (6) to expand human presence and activity beyond Earth orbit into the solar system. (White House, 1988)

Air Force Policy

The national and DoD policies provide guidance for present and future research. The directives also states that "space leadership" is fundamental and necessary for all space activities (White House, 1988). The DoD is taking the role of space leadership in the area of national security, and the Air Force is taking a leading role. The Air Force is to be the "major provider of future space forces" according to the Air Force's Space Policy released in April 1989 (Bird, 1989:3).

In an interview with Air Force Magazine, then Secretary Aldridge commented that the "United States was on the verge of a strong resurgence in space" (Canan, 1988:68) and that space is the future of the Air Force (Canan, 1988:73). Aldridge's main concern was to insure "that the Air Force has a goal in mind for space" and that we make a plan to reach that goal (Canan, 1988:73). According to Aldridge, "the Air Force has been the lead service" from the earliest days of space applications (Aldridge, 1988:13). He continues "that the future of the Air Force is inextricably tied to space [Aldridge, 1988:19]."

The Air Force policy includes four roles for space. The Air Force will 1) provide space control operations; 2) acquire and operate space-based defense assets and, if necessary, space-based weapons; 3) continue to operate systems for "navigation, meteorology, tactical warning and attack assessment" and communication; and 4) provide launch and on-orbit support (Dept of the Air Force, 1982a; HQ USAF, 1988).

Launch and on-orbit support directly relate to the Air Force Civil Engineering mission. The traditional mission of CE is a support role. The Engineering and Services (E&S) Space Support Policy reflects this mission. This policy, signed by then Director of Engineering and Services Major General George Ellis, states, "we must also be poised to undertake the natural extensions of these roles into the non-terrestrial environments [E&S, HQ USAF, undated]." To carry out its roles, E&S will:

> Achieve early involvement in space concept development and systems planning;
> Provide support to the ground components of military space capabilities;
> Provide the required standards of facility reliability and performance;
> Develop capabilities to construct, operate, maintain and repair facilities in space;
> Develop capabilities to support space-based operations with billeting, food services and mortuary affairs functions.
> (E&S, HQ USAF, undated)

This policy gives goals and direction for CE in space. The immediate needs and plan to reach these goals must be determined.

The E&S Space Plans Office heads up the E&S's role development in space. The E&S's function is to be the center of space-related knowledge, coordinate activities, and develop plans and requirements (Ellis, 1987). The CE Space Plans Office at Headquarters, Air Force Space Command (HQ AFSPACECOM) manages the growing technology and increasing activity in space for the Air Force. The Engineering and Services Space Liaison Group (ESSLG) provide interaction between major space-related agencies. The ESSLG acts as a liaison between AFSPACECOM, the Air Staff and the E&S community (Ellis, 1987).

Policy Issues

The ESSLG is addressing several topics according to Lt Col Felix Uhlik, Chief, CE Space Plans Branch at Air Force Space Command. Some issues are: space facility acquisition, utility reliability, facility O&M, fire protection, manned mission support and the environmental impact of space operations (Uhlik, 1989).

A key issue to be faced for expanded operations in space is the commitment of resources versus the payback received. Resources are critical for space. The military and NASA compete for similar resources. (Uhlik, 1989).

Different opinions on what is a space facility versus a space system versus space equipment contribute to confusion of who has what responsibility (Uhlik, 1989). Will the space station be considered a space ship or a facility? Who will be responsible for the station? These are issues to be addressed.

An additional issue is the perception of space, according to Captain Wilder, Deputy Chief, CE Space Operations Branch at Air Force Space Command. Space must be viewed as an "operating medium" or a simple "extension of the atmosphere [Wilder, 1989]."

Manned Space Missions. There is continued controversy over whether man is required in space. NASA Liaison Officer Sam Anzalone said NASA tends toward the man in space aspect at this time (Anzalone, 1989). The military, however, tends toward unmanned operations. The Technology 2000 report states,

> In SPACE, the trends are clearly toward man in space, but not until after the year 2000. The space station as a NASA initiative will occur before then, but DoD involvement is best characterized as interested but not pushing hard. (Technology 2000, 1988:5)

[NOTE: The Technology 2000 report is a contracted study conducted by the New Mexico Engineering Research Institute/Readiness Technical Analysis Group (NMERI/RTAG) for the Director of Engineering and Services.] Captain Martin, Deputy Chief, CE Space Plans Branch, Air Force Space Command, agreed. By controlling satellites and other space equipment from Earth, there should not be a need for man in space. We are capable of meeting today's mission and the mission of the immediate future from Earth. "We just have to get better at doing it [Martin, 1989]."

The combination of outer space activities and improved ground support facilities operations is the responsibility of the AFSPACECOM CE plans section. Lt Col Felix Uhlik, Chief of the AFSPACECOM CE Plans office believes CE's role should be a continuation of the traditional ground support role and preparation for extra-terrestrial domains if military missions are necessary (Uhlik, 1989). Preparation for space missions is of vital importance. E&S must be prepared to assume their responsibilities or another function, such as logistics, may take over (Uhlik, 1989). How CE assumes the responsibilities is also important. According to Mr. Mike Bratlien, Chief of the HQ AFSPACECOM CE Operations branch, by getting too much too fast people will get nervous - by going too slow CE will miss out (Bratlien, 1989).

Conclusions

Engineering and Services has a stated policy and goals for space. There is not a plan on how to achieve those goals at this time.

Tactical implementation of space operations needs to be addressed. These goals must develop into plans and procedures for space operations.

CE does not have an active role in outer space activities today. The current major concern is for ground based space support facilities. Efforts should be geared to improving the operational capability of ground based support facilities (Wilder, 1989).

Until space systems are defined as equipment, facilities or a space ship, complete roles and plans will be hard to develop. Different organizations are responsible for differing systems. An authority must decide who will have responsibilities for which systems.

The ESSLG is a liaison group at this time. This group acts as a focal point for information and coordination. However, no office exists to determine plans and actions needed to prepare CE for a space related mission. Such an office would also be responsible for funding and identifying and providing requirements for approval. The CE Space Plans office at HQ AFSPACECOM should be given more authority to develop the long range plans for Civil Engineering in space. That office must work with other agencies to concentrate space knowledge and action into a single focal point. The Space Plans office could work with NASA to reduce duplicating research and competing for resources.

III. Training

Introduction

The era is coming when man in space will provide a greater range of tasks than before (Pabich, 1986:13-15). Man must be trained to perform those tasks. This chapter discusses aspects of training for working in the space environment. The methods of training and the levels of education are examined. The primary focus is training for maintenance operations in the space environment. Training is only necessary if man is in space. Therefore, the last section reviews man in space. Conclusions are made for CE's requirements.

Training Requirements

Training must begin with a knowledge of the environment. Space offers differing conditions which might affect actions common on Earth. It will be necessary to train for the known conditions and prepare to handle unknown circumstances.

Education. Training begins with education of the space environment. Astronauts study astronomy, physics, meteorology, guidance and navigation, and computers (Harper, 1987:52). Pilots, navigators and aviators undergo similar education during flight training. Flyers are a natural choice for space missions. According to Army Captain Charles Gemar, "Being an astronaut and flying in the orbiter are flying jobs. You have to be accustomed to a high-altitude, high-speed environment [Harper, 1987:52]." Presently, all space flight crews consists of "highly skilled and extremely motivated individuals all with advanced university degrees [Junge, 1983:556]." These highly skilled personnel are trained at a high cost for specific purposes. Training and education costs will need to be reduced.

Physical Experience. Another way to review the requirements of space is through past physical experience. A space mission, flown October 1985, further tested an astronaut's ability to assemble space structures (Lozar and Stephenson, 1987:51). The Experimental Assembly of Structures in EVA (EASE) and Assembly Concept for Construction of Erectable Space Structures (ACCESS) tasks were successful. Studies measuring man's productivity assembling structures in space during the Skylab missions show "no physical limitations to man's ability to perform effectively in space for long periods of time [Disher, 1975:7]." These missions also showed that training in "neutral buoyancy tanks [similar to the Johnson Space Center facility] is a reasonable predictor of mission element times for EVA [Lozar and Stephenson, 1987:55]."

Training must also focus on the application of specialized technical knowledge of the space environment (Wile, 1988:30). One such factor is zero gravity in space. The weightlessness of space creates special conditions for maintenance (Junge, 1983:552).

Training Methods

The training methods are important factors in preparing crews for missions. Education and experience provide the best method of training.

Education. U.S. Army Lt Col Joseph Cushieri believes the Army will have to attract more individuals with science degrees and computer skills for space applications. Extended training in the space sciences and technology will provide a "nucleus of a `hi-tech' [Army] Corps of Engineers" for the future. To help achieve this result, the Army is placing an emphasis on space skills in their curriculum at the Engineer's School (Cushieri, 1986:8).

The Air Force currently provides several formal training avenues for space systems. Training and education is available through an undergraduate Space Operations course at Lowry AFB, a B.S. in Astronautical Engineering from the Air Force Academy, some professional continuing education courses through the Academy and AFSPACECOM and two masters degree programs, Space Facilities and Astronautical Engineering, at the Air Force Institute of Technology (AFIT). Graduates of these programs are then slotted into positions requiring this education.

Additionally, the Engineering and Services Space Liaison Group meetings provide a form of on-the-job training (OJT) and awareness of space-related topics to the E&S community (Uhlik, 1989). Many of the technicians receive OJT while stationed at Vandenberg AFB and Falcon AFB. Working around launch facilities and tracking stations provide a better understanding of the systems and may be the best OJT education possible (Martin, 1989).

<u>Experience</u>. Two systems exist for training in the weightless environment. The Martin Marietta Space Operations Simulator (SOS) trains astronauts using the Man Maneuvering Unit (MMU). The SOS provides realistic training for the gravity-free environment and use of the MMU under operational conditions. Training simulates typical maintenance/construction activities that can be expected in space (Hartley, 1985:29-33).

The second system is the Johnson Space Center weightless-environment training facility. Army Colonel Sherwood Spring trained using Johnson Space Center's facility before his two walks in space. He commented, "The real thing followed the simulator training almost 100 percent [Harper, 1987:51]." Spring admitted that it was physically demanding and sometimes painful to train for extra vehicular activities (EVA) (Harper, 1987:51).

Further Requirements

Captain Wilder, a graduate of the Space Facilities program at AFIT, believes the educational programs should be tailored to the specific needs of Space Command. A course in launch facility complexes and a feedback system from graduates would improve the AFIT programs and research (Wilder, 1989).

Mr. Bratlien's (CE Operations Chief at HQ AFSPACECOM) concern is a need to develop better training procedures for utilities operations and maintenance. Mr. Bratlien also believes the training must include checklists, proficiency training (similar to flight crews) and retesting. Additionally, improved systems designs would include human factors to reduce the amount and possibility of human error (Bratlien, 1989).

Capt Wilder states a need for a strong emphasis on certification of power systems. Operational power systems are the most critical factor in space-related maintenance within Space Command. The training must emphasize ways and capabilities to keep power systems operational (Wilder, 1989).

Other training, primarily in the area of astronaut training and space operations, is available through NASA programs. Mr. Sam Anzalone, the NASA liaison to the AFSPACECOM, said that NASA works with military personnel to carry out their work and provides positions whereby military personnel are exposed to and work with the people and technology involved in space. However, there is no formal alliance between the Air Force and NASA for any formal training (Anzalone, 1989).

Man in Space

Different scenarios can validate the need for man in space. Training is needed for man to operate in space. Without man in space, training would be limited to control of unmanned systems.

A key viewpoint is that there are no unmanned space programs. Unmanned spacecraft (rockets) require sizeable ground crews to operate and manipulate the systems (AFSTC, 1982:1-2). It would be hard to justify the need for man in space on national security grounds, since much of today's space-related military operations use unmanned systems (Koser, 1986:27). But to fully utilize the potential of space, it is necessary to have man in space (Fallstead, 1985:23).

Having man in the loop provides for two major advantages. First, by using the EVA, man can perform unique servicing operations which the robotic manipulator can not perform (Herring, 1988:39). Secondly is man's ingenuity. The damage to Skylab in 1973 was overcome by man's ingenuity and stamina to repair the space station. Without man there, robotic functions would not have been sufficient to recover the station (AFSTC, 1982:1-1).

Man has the adaptive ability to suit any situation. It is man's ability to learn much faster than a machine (Gibson, 1985: 97) that keeps man a viable part of the loop. Experiences by NASA and Soviet personnel have shown "that the human eye is more readily adaptable to situation-sensitive activities" than other vision monitoring systems (Eubanks and Smith, 1987:10). It is man's adaptability which makes him a superb "black box" for problems and provides the following advantages:

1. Great flexibility in performing a large variety of tasks,
2. Innate adaptive intelligence to utilize his flexibility, and
3. His analyses and functions are only limited by his tools (AFSTC, 1982:1-3).

Man is needed for his cognitive skills and will be used for judgement and decision-making skills (Gibson, 1985:97).

Although the Air Force conducts research in developing technology, most of the research is through defense/government contracts and private sector innovations. NASA provides the technology push by continuing to operationally deploy men in space (Wilder, 1989). NASA's plans for the space station `Freedom' will be delivered by both manned and unmanned vehicles (Anzalone, 1989). The ability to construct, man and support the space station will provide another technology push today needed for future operations. NASA's manned space program is the only U. S. technology being established today (Anzalone, 1989).

Conclusions

Presently, there is a strong emphasis on astronauts having a higher education in the sciences. This is necessary because space is a relatively new and dangerous field. When space is a more operational environment, this requirement will have to be reviewed. Trained personnel with a lessor education may be beneficial for space construction and maintenance. Technicians in CE today do not require higher education to perform their mission. This may be true for space missions in the future. Alleviating the education requirement would provide a broader range of personnel to perform maintenance actions.

The Army continues to do extensive research in the technology, training and personnel requirements for space. The Army appears to be trying to develop a `Corps of Engineers' capable of operating in space. Their continued efforts may make them the lead service in space applications. The Air Force must work with the Army or work harder toward space in the area of maintenance applications. Failure to take action now may leave the Air Force out of the long-term developments.

The capability exist to train for the weightless environment. As more is learned about space, more training simulators and procedures should be developed. Training closes the loop of man and machine compatibility. This training provides "the best simulation of the operational environment" possible (White, 1972:253-264). Simulators for facility construction, assembly, repair and maintenance are needed. A facility similar to the Climatic hangar at Eglin AFB could be built to train CE personnel in conditions of weightlessness, low air pressure and temperature extremes. Use of simulators continues to be the best method of training available.

The training provided by the Air Force is suitable at this time. The number of personnel being taught is sufficient for today's needs. Plans must be made now to increase the training quotas. The quotas should increase in approximately 3 years. This time frame would provide more personnel when NASA is ready to put the space station in orbit.

Classes are continually reviewed for adequacy and updated as needed. As Captain Wilder suggests, a course on launch complexes would be beneficial to Air Force Space Command. Possibly, the course could be constructed as a continuing education course to instruct officers and enlisted who are involved in maintaining these facilities.

The proficiency of power systems personnel is not adequate. Power failures which are not quickly resolved cause major problems for CE personnel. Maintenance personnel require improved training and education on supporting the power systems.

The Air Force and NASA, along with other DoD agencies, need to work together on training of personnel. Consolidation of effort would reduce costs and improve overall proficiency.

Man's use of space is not dependant on man being in space. Man is needed and will eventually operate in the space environment. Environmental and cost factors will have to be overcome first. The CE mission for space facilities will be limited to ground support facilities until the military has a need for structures in space.

The space environment poses additional hazards which man can not easily overcome at this time. Until these hazards can be removed, space will be a very limited operational area for man.

IV. Technology

Introduction

Technology is an important factor in the use of space. Either manned or unmanned missions require technology to use space. This next section reviews why we need technology, what space technology includes, and the technological advances needed in space.

Why the Need for Technology

One of the key aspects to space operations is technology. Technology will provide reliable facilities and systems in space. Realizing this need, the DoD will "conduct research and technology development, in cooperation with other research organizations, to preserve and enhance a strong technology base" and emphasize national security capabilities (DoD, 1987:2). The need for this technology development is clear although what the technology will consist of is not as clear. This is reflected in the Technology 2000 report.

> Technology will shape the future and key decision makers of Air Force Engineering and Services (E&S) could benefit from a clear look at the changes which will be coming from now to the year 2000. Unfortunately, the crystal ball is cloudy and the future must be estimated from incomplete data. (Technology 2000, 1988:1)

Secretary of the Air Force Aldridge emphasized why we need technology. He commented that our space programs have been limited by our technical capabilities. But we now face a different situation with new and varied technology available (Aldridge, 1988:13-14). Wile states the problem is not the development of technology but the transfer of the technology to the space environment. This problem can be overcome by extending logistic principles to the space systems. Depot-level maintenance, life cycle costs and logistic support analysis can be applied to transport systems for optimum design. (Wile, 1988: 30-33). Transport of construction materials will have to be from Earth to low orbit (Fallstead, 1985:23). Materials available from the moon could be mined and used to make the necessary construction materials (Shevchenko, 1988:22-25). Secretary of Defense Carlucci emphasized that "the importance of space will increase dramatically . . . if we are to exploit the many emerging technologies" available for military strategy (Carlucci, 1988:2).

Benefits of Technology

We can often adapt space technology for improvements on Earth. Much of the higher technology used on Earth was developed for space. A good example is the nickel-cadmium batteries developed for satellites (Bratlien, 1989). Air breathing apparatus used by fire fighters (developed as a result of similar work for space) and material used to cover the Silverdome, in Pontiac Michigan, (which was made from material used to make EVA suits) are other examples (Anzalone, 1989). Communications, command and control operations used by the Navy rely on space-based assets (Anzalone, 1989). This technology was learned in the 1970's.

New developments on Earth can also be used in space. Examples are fiber optics, composites semiconductors and high speed integrated circuits (Herring, 1988:38). The Air Force has made "advances in the fields of metallurgy, space medicine, and aeronautical engineering" as a result of its work toward space operations (Cushieri, 1986:3).

Technological Needs

"The technology for designing and building structures in space is immature," according to a study by the U.S. Army Construction Engineering Research Laboratory (USA-CERL) (Eubanks and Smith, 1987:5). A plan for space structures would move space construction technology to the fore-front of research and development activities (Lozar and Stephenson, 1987:7). Little research has been done concerning permanent stations in space because of the recent focus on space shuttle technology (Eubanks and Smith, 1987:5).

Space Structures. Presently, there are two main thoughts for construction technology: large space structures (LSS) and deployable structures. LSS are transported in stages and when assembled are larger than the vehicle which carried them into space (Lozar and Stephenson, 1987:10). Eubanks and Smith believe military applications will require LSSs be designed as a family of platforms for specific operational requirements (Eubanks and Smith, 1987:8). The LSS require assembly in space.

Deployable structures are those which automatically or mechanically expand when deployed from either the space shuttle or an unmanned rocket (e.g., satellites) (Lozar and Stephenson, 1987:25). The *Challenger* accident renewed an interest in deployable structures (Eubanks and Smith, 1987:7) for using unmanned rockets to reduce the risk of human life. No one approach (LSS or Deployable) is favored over the other for the space station construction (Lozar and Stephenson, 1987:23).

Power Reliability. The major need in the area of technology for Space Command Civil Engineering returns again to power reliability.

Captain Wilder believes power reliability is the key factor in Space Command today. This includes systems for power distribution; redundant power systems; and preventive, corrective, and anticipative maintenance programs. Any power outage at a ground control support facility of more than 5 minutes is briefed to the Commander of Space Command daily (Wilder, 1989). From this aspect, Mr.Bratlien would like to develop five-9 reliability. That is 99.999% assurance that we will have uninterrupted power to the ground support facilities at all times (Bratlien, 1989).

Both, Mr. Bratlien and Capt Wilder, feel that the next major step in space operations is the operational launch of space vehicles. Engineering must develop methods to make launch facilities capable of relaunch, reduce turn-around-time and create "normalized" procedures for space launch activities. Launch of a space vehicle should become as routine as aircraft take-offs (Bratlien, 1989; Wilder, 1989).

Developing Technologies. Another development would be the use of intelligent computer programs. Expert systems could perform many routine tasks.

> The most significant challenge in technological evolution will come in the area of expert systems. Challenging tasks to be faced include detailed task planning, spatial coordination of servicing mechanisms, control of multi-arm and multi-finger dexterous manipulators, failure recognition and recover, support of complex operational decisions, and lastly, development of systems which are capable of learning. (Gibson, 1985:97)

Lozar and Stephenson provide other areas of technology improvements which must be addressed. The following summarizes these areas.

1. Recent technologies:

    - mechanical/structural properties of materials,

- atomic oxygen test facilities and effects of atomic oxygen on materials, and
- analytical methods for material testing.

2. Materials processing:
   - low-Earth orbit/commercial processing,
   - aerospace materials, and
   - materials for structures.
3. Lunar materials for construction:
   - materials processing on the moon,
   - mining operations on the moon,
   - construction on the moon's surface, and
   - transport of lunar materials.
4. Research issues (for further R & D):
   - robotics/human/machine interface for construction,
   - expert systems/artificial intelligence,
   - radiation/cosmic rays,
   - cold/vacuum problems in composite materials, and
   - stability/flexibility in structures (Lozar and Stephenson, 1987:10-21).

Organizations within the Air Force looking at new technological developments include the Air Force Space Technology Center (AFSTC), the Air Force Office of Scientific Research (AFOSR), and the Air Force Weapons Laboratory (AFWL); and the NMERI/RTAG on Air Force contract (Uhlik, 1989).

CE can benefit through better operations and maintenance (as seen with power reliability), improved and more capable launch complexes, improved support to ground facilities and long term R & D efforts (Bratlien, 1989).

Environment

Other concerns are for the hazards of the space environment. Atomic oxygen degradation causes a deterioration of the materials and can be quite dangerous over long periods of time (Lozar and Stephenson, 1987:22) Harmful, free-floating dust particles from construction in the weightless environment poses problems to workers in the space environment (Lozar and Stephenson, 1987:62).

The decrease in bone mass (decalcification), hormone and electrolyte imbalances, and unstable protein and carbohydrate states are aspects of space's effect on the human body (Fallstead, 1985:24) which must be overcome if man is to spend long periods of time in space.

Still aspects from harmful radiation, radiation protection, resupply and crew needs, and life support systems are areas where the technology must develop to make space a habitable environment (AFSTC, 1982:1-8; Lozar and Stephenson, 1987:62). Other areas where new technology could be successful are food services, medical/health, environmental and biological/physiological sciences.

Conclusions

There is much technology available today which affects the space program. Technological advances will continue to aid efforts to improve capabilities on Earth. The technology transfer will continue to improve the Earth environment.

Logistical problems remain concerning transporting materials. Work will continue using both LSS and deployable structures until one method is chosen. Use of LSS could define the construction of space structures as one role for Civil Engineering. Both LSS and deployable structures will require some form of maintenance. The large space structures will require construction as well. Civil Engineers must train to maintain and construct these structures in space.

The Army has done more work toward space operations and research than the other services. The Air Force must use the knowledge of the Army's research and close the gap between the services.

Power reliability remains a main concern of the people at Space Command. Their concern is more for the present and near term problems which must be solved before trying to make space an operational environment. Resolving the problem of power reliability depends on developing better systems and integrating technology.

V. Maintenance

Introduction

Facility maintenance is the primary role of Civil Engineering for air bases today. Space platforms will need some form of maintenance and/or repair. Maintenance in space may be a CE mission in the future. CE already maintains terrestrial space support facilities. Space-based facilities will require preventive maintenance and corrective maintenance. This will provide a challenge to meet varying requirements of the systems (Wile, 1988:30).

The concepts of preventive and corrective maintenance is not new to the Civil Engineer. The challenge of performing in space is new and opportunities exist. The Technology 2000 report states that opportunities for space operations are "virtually unlimited." Terrestrial bases and ground stations are inherently the support responsibility of E&S (Technology 2000, 1988:5). This chapter reviews maintenance concepts for space. Conclusions about space maintenance are presented.

Maintenance

This section examines some of the maintenance theories involved with space systems. Maintenance includes the preventive and periodic work necessary to ensure the maximum life of the system. Maintenance is usually scheduled to replace old or worn parts, filters or fluids. Maintenance is scheduled in anticipation of the unit failing and is a preventive measure. The same theory should be applied to space systems. Maintaining space systems must include both space-based and ground launch facilities (Classen and Bentall, 1988:195) if the mission is to be successful.

There were no means of either corrective or preventive maintenance on space-based systems just 10 years ago (Herring, 1988:37). The Skylab mission was our first introduction to space maintenance. Astronauts in Skylab performed planned and unplanned corrective maintenance. Their experience "will have far reaching effects on the design approach to in-flight repair, servicing, and assembly of future spacecraft [Disher, 1975:4-5]."

The next significant maintaining experience occurred on the Solar Max mission. [Solar Max was the Solar Maximum mission satellite.] Solar max was the first satellite designed to be retrieved and repaired in-orbit (Haise, 1982:5). Solar Max was the first experiment in recurring or planned space maintenance. When Solar Max was retrieved by the shuttle in 1984, it began a new era in space logistics (Bowman, 1986:13) and proved that various levels of space maintenance is possible. The Space Transportation System (STS or space shuttle) and plans for a space station increase the reality being able to service orbiting equipment (Herring, 1988:37).

Introduction to Space Maintenance Concepts. Unique perations include assembly, maintenance and servicing of space-based systems. "Space maintenance is the process by which preventive or corrective maintenance actions are performed on a space-based system [Wile, 1988:31]." Maintenance of space systems should increase their life-cycle, allow for simpler systems, reduce the amount of redundancy required and lower the overall cost of the equipment (Fuchs, 1984:106). Space maintenance concepts can be applied to three areas:

1. Modifications to the space station (including preventive maintenance),
2. Repair of satellites on-orbit, and
3. Assembly of large space structures (NASA, 1984:2-6).

Dr. Gerald Leigh, from NMERI/RTAG posed a variation to typical maintenance procedures. He said CE does preventive maintenance in anticipation of failure and repairs the machine when it breaks. In space, the risk and cost of failure may be too high to follow this procedure. Instead there must be a system of continual inspection and prediction to anticipate and prevent failures. We must replace or modify the system before it breaks. This concept is a more stringent concept of predictive maintenance (Leigh, 1989).

Preventative maintenance is the most common form of maintenance. The concept of preventive maintenance is being employed by the European Space Agency (ESA). Friedrich and others discuss the scenario the ESA will employ. The ESA intends to deploy a Man-Tended Free Flyer (MTFF) which is scheduled for maintenance every 6 months. Servicing will be by man in a pressurized module and robotics. Servicing will be conducted while the MTFF is connected to a servicing base (Friedrich and others, 1988:27).

Maintenance will have to include retesting and feedback. Retesting ensures the part repaired or replaced during the maintenance activity is acceptable and functioning. Feedback enables the maintenance personnel to include improvements in the future design of a system (White, 1972:263-264). By including retesting and feedback as part of routine maintenance activities, it will enable us to know that satellites or other systems returned to space are operational (Fuchs, 1984:107).

Prominent Methods for Space Maintenance. There are several methods, both preventive and corrective, being considered for space maintenance. Maintenance could be performed in orbital repair facilities, while in orbit with the system or, retrieved for ground repair (Herring, 1988:38).

Several scenarios can develop for conducting space maintenance. Man could deploy from a separate craft (station or shuttle) in a synchronous orbit to repair a system. The shuttle could be used to retrieve the space system for repairs while on the shuttle. Or, the shuttle could retrieve the system to return it for repair on Earth.

Orbital Replacement Units (ORUs). ORUs are "spare parts used to perform either scheduled or unscheduled removals and replacements [Herring, 1988:37]." Instruments are designed for modular function and are sub-divided into the more frequent failure modes for easy replacement (Hathaway, 1988:192). Storage cost are associated with the need of the unit versus the anticipated failure rate and redundancy of the system (Winchell, 1987:145-150). Life cycle costs would depend on the trade off costs of the required unit parts costs and the spares storage costs (Winchell, 1987:145) and may eliminate or reduce storage cost. Costs could be reduced by consolidating supplies under a central system (Savage, 1987:154). ORUs fit either scenario mentioned earlier but are best associated with replacement from an orbiter. Particularly where retrieval of the system would not be feasible for replacing component parts.

Robotics. Robotic theory involves removing man from the environment. The level of robotic and human interface depends on the intelligence capability of the robotic system. Robot operations involve artificial intelligence systems to control robot movement. The intelligence systems make robots good for routine servicing (Herring, 1988:39). Robots can perform repetitive tasks associated with the assembly and preventive maintenance of space structures (Eubanks and Smith, 1987:10). Assembly actions such as riveting bolts along structures, connecting assembled units and moving materials would be ideal for robots.

"Telerobotic dextrous manipulators" (remote controlled robots) can perform some maintenance actions. Actions involving human interface such as locating specific joints and arranging materials in the proper assembly sequence suit the use of these robots. These manipulators operate from remote locations and provide more flexibility (O'Hara, 1987:791). However, these manipulators have problems with remote vision, time delays and control (O'Hara, 1987:791).

Robotic costs are offset by the savings in human life and a life support system (Wile, 1988:32). Robotics are the only action which can totally remove man from the space environment. Robotics could be used from the Earth to totally remove man. More practical, though, is the use of robots from an orbiter.

Space Station Maintenance. The concept of a permanently manned space station is being developed for operational deployment in the next 10 years. On-orbit assembly of the space station should begin in the 1990's (Bowman, 1986:13). A space station will provide new capabilities and responsibilities for space maintenance. The station will be a base for on-orbit service or repair and will lengthen the life and applications of many space systems (Levy and others, 1986:571; Herring, 1988:37).

A space station will provide other opportunities in space. We are presently limited by payload sizes, mission durations, and control maneuvers. However, the space station provides a method to overcome such constraints (Fuchs, 1984:105). A space station allows for transporting and storing components in space until needed for a mission. Larger structures could be assembled from components stored at the space station.

The space station will provide support for on-orbit repair and storage of ORUs (Herring, 1988:38) and will allow for a "fly to failure" mode (Herring, 1988:39). The ability to do repairs in space reduces some of the need for preventive maintenance. A space station may function as a depot level maintenance activity where failed parts are returned and either repaired at the space station or returned to Earth for repair (Wyatt, 1987:18). Orbital Maneuvering Vehicles (OMVs) can retrieve failed parts and return them to the space station for corrective maintenance (Herring, 1988:39).

One possible idea is a large inflatable space "hangar" where crews can work inside a safe, pressurized module and use semi-EVA. Semi-EVA provides better dexterity and efficiency than full EVA or robotics (Ohkami and others, 1986:1939-1944). The hangar must develop technically before it can be deployed.

On-Orbit Servicing. Probably the most realistic option is on-orbit servicing and repair. Herring states that on-orbit servicing can include items such as repair of damaged parts, refurbishment of consumable items (i. e., cryogenics, batteries...), and technology upgrades. Servicing systems while on orbit allows for maintenance actions to occur without disrupting the orbit of the systems under repair (Herring, 1988:39).

Transporting the source of maintenance to the equipment poses a problem with this method. OMVs could deliver the servicing mechanism (Herring, 1988:39) to the orbiting equipment. As an example, the Manned Maneuvering Unit (MMU) was used to retrieve the Solar Max (Hartley, 1985:29-33).

Similar maintenance activities can be performed from the shuttle or other orbiter base. Based on the previous experience of shuttle flights and the success of the Solar Max mission, on-orbit repair or retrieval appears to be the most viable method for space maintenance.

Conclusions

Maintenance of space systems is still an incomplete and open subject. At present, "the jury is still out" on how space maintenance will be done (Uhlik, 1989). Ground support facilities will still fall in the domain of the traditional role of the Civil Engineer and for now, remain the most important work to support space operations.

Maintenance procedures will be necessary in space. Limited contact with space systems places preventive maintenance on a higher priority. Methods exist for maintenance but must be refined to improve reliability and accessibility of the systems.

The maintenance methods given in this chapter appear closer to aircraft maintenance than facility maintenance. Modified concepts used for aircraft and communications equipment are recommended for space (Wyatt, 1987:18). These concepts could eliminate the need for Civil Engineering to perform maintenance actions in space. Eliminating the CE maintenance function would reduce the CE role to only support of ground facilities and, possibly, construction in space.

Robots will be used in space. Robotics provide most of the capabilities of man. However, using robots reduces risks to man. The field of robotics is increasing with intelligent computer systems. The automated systems may replace man's function for routine servicing actions.

NASA will have to determine the uses of the space station. It could be used for scientific research, as a maintenance depot or storage location for space spare parts. The space station will be the next major deployment in space. As an orbiting structure, it may be considered the first space facility. Maintenance of the space station will provide a guide for future space facilities maintenance.

On-orbit servicing has been performed in space. Using today's technology is a major advantage of on-orbit servicing. This method provides the capability today to repair or service space systems. On-orbit servicing may also take advantage of robotics and the space station in the future. Combining the methods may provide the best possible maintenance procedures.

VI. Forecasts

Introduction

This chapter forecasts actions to prepare Civil Engineering for a challenging role in space. As General H. H. "Hap" Arnold said, "Any Air Force which does not keep its doctrines ahead of its equipment, and its vision far into the future, can only delude the nation into a false sense of security [Dept of the Air Force, 1984:4-7]." President Kennedy set a goal for man on the moon, which was achieved when the United States reached the moon in 1969 in Apollo 11. From this visionary role, it is necessary to look to the future of space and what CE must do to prepare for space operations.

Future Developments

This section provides the forecasts for immediate, near term and long range goals. Each area may covers many of the topic areas discussed in previous chapters.

Immediate. This section forecasts actions necessary within the next 1 - 3 years.

The Role of Civil Engineering. General policy statements and overall objectives exist for the mission of Civil Engineering for the support of space-based operations. Doctrine is being developed but has not been addressed in regulations and manuals. General doctrine has been developed at the Air Force level but not for Civil Engineering (Dept of the Air Force, 1982a). Civil Engineering is addressing doctrine overall and must include space. The policy and doctrine must be further refined. To state the Civil Engineering roles, responsibilities and methods in space operations is not sufficient. Failure to clearly define the role and take charge of the responsibility will leave tasks normally associated with CE to the Army, to scientists, to logisticians or to systems engineers. Specific goals must be set. The goals must provide a blueprint for tactical implementation. The goals must develop into plans and requirements. These plans must include anticipated methods of maintenance, design requirements for maintenance, construction capabilities and possibilities in the space environment.

Responsible Office. The formation of a knowledge base is already in progress. The Space Command CE Plans office (AFSPACECOM/DEX) and the formulation of the ESSLG provide a knowledge base of personnel, data and information. A greater emphasis needs to be placed on planning of total space systems to include funding for support facilities. The emphasis on planning should be one of the plans office's first concerns.

Definite authority must be given to a section who will be responsible for manning, identifying requirements, budgeting for new systems and managing the program. This office should be responsible for coordination and liaison of space-related information between private industry, NASA and the DoD. The ESSLG can be used as the foundation and develop as a Space Steering Group.

Power Reliability. The most significant concern within Space Command Civil Engineering is the reliability of power systems supporting ground facilities. This applies to launch support facilities, ground support facilities and tracking stations. Loss of electrical power means a loss of control or communication and is extremely detrimental to space operations and space systems. Redundant and back-up systems help but are not the total solution. Technology needs to develop capable power supply systems. Recent innovations with semiconductors may help. The Air Force should sponsor developmental research for the purpose of continued and reliable power supply.

Additionally, special requirements need to be developed for the power systems technicians in Space Command. The special technical training should address the needs of these unique systems. Development of new systems will benefit the reliability and maintenance capability for other ground facilities. If necessary, the work could be contracted to retain the required skills and knowledge. Much of the non-military work of Civil Engineering is being contracted out. A similar option might be used for maintaining complex power systems. The knowledge and experience could be hired and retained through responsive contractors.

Near Term. Much of the work around space operations involves growing technology. As technology develops, the capabilities and possibilities in space will continue to increase. Most of these capabilities should develop in the next 3 - 10 years.

Status of Space Command. Space Command, one of the major commands in the Air Force, is a young command. Similar to the development of the Air Force from the Army Air Corps, Space Command may develop into a separate agency. The Air Force emerged as a growing technology in the early 20th century. Through the study of air power and uses of the airplane, the important role of the Air Force developed. As technology of space and the use of space for military missions grow, it may be necessary to develop a separate space service.

Space Command could combine with NASA to form a space agency. Combining these agencies would provide the knowledge and systems available from both sources. This combination would help achieve national goals in space, both military and non-military. A single service responsible for space would eliminate any possible conflict for similar resources. This would also allow for support equipment and funding requirements to be under one deputation rather than spread through different agencies in the government.

Training. The amount of training and education should increase as knowledge and use of space increases. Training will have to be on a more routine basis to train more personnel. A lesser emphasis on education will open up space operations to more personnel. Use of more personnel will increase the training requirement and reduce the need for higher educational standards. This will allow for technicians to be used and leave the astronauts to pilot the transport vehicle. Plans and programs should be developed now so that the educational programs can be operational in the near term.

Simulation provides the best training methods possible at this time. Simulators are used to represent the environment. A low pressure facility is needed to simulate the space atmosphere.

Changes in education should include courses in Launch Complex Systems and Facilities, Space Construction and should include a method for feedback from the field. The educational programs must utilize the growing technology and support the engineering mission. The Air Force could combine with NASA, USA-CERL, and other agencies to work together on space technology.

Technology. The Technology 2000 report by NMERI/RTAG provides insight into some of the technological advances needed. Using the work of NMERI/RTAG as a bases, Civil Engineering will be able to increase its capability in several areas. Development of semiconductors may influence space travel. Additionally, the gravity-free environment of space may make space manufacturing a viable and appealing venture. Construction materials might be developed in space which can be used on Earth. The weightlessness may provide answers in materials research and development for products to be used on Earth. Suits made for the space environment may be adaptable to use on Earth in areas of fire protection, environmental protection and disease containment. Other composite materials may make light-weight, high-strength materials available for manufacturing.

The use of artificial intelligence and robots could preclude the need for man in space. Artificial intelligence and robotics could be used with unmanned missions and accomplish many of the same goals as manned missions. Use of these systems will reduce the risk to man.

Maintenance. The concept and capabilities in the area of maintenance remain wide-open. Action should be taken to improving the design of satellites and other space systems to take advantage of the knowledge and capability of on-orbit retrieval. Funding and frequency of retrieval missions may preclude this work as a regular occurrence. However, work must begin now so that satellites can be retrieved and repaired in 10 years. The concepts applied to space systems may also be applied to Earth systems to improve the design and maintenance of many systems in use today. The primary method of space systems maintenance which we are capable of today and should use in the future is on-orbit retrieval.

Civil Engineering must do research and development on space facilities maintenance. Present space maintenance procedures are variations of aircraft maintenance. The role for CE will not develop without defining a need for Civil Engineering in space.

Long Range Goals. Exploration and habitation of space is a long term goal for the nation. It may even become a necessity to allow for a growing population on Earth, to assist in providing a food supply for that population and as a possible escape from the pollution which is ruining our environment. However, these events yet remain in the long term beyond the next 10 years.

Training. The long range goals in training are dependent on the technological developments. Today, astronauts are highly educated personnel, trained for specific functions. The future will see a time when each aspect of the space mission is specialized. Astronauts may be the pilots and navigators, but other personnel will be involved in the space mission. Passengers to a space station will include doctors, scientists, metallurgists and even laborers. None of these personnel will have nor require astronaut skills.

Programs will develop to train personnel in living and working in the space environment. Providing a "space hangar" simulating the space environment will be the best way to train non-technical people for working in the space environment.

Extra-Terrestrial Basing. Concepts for space stations which provide a form of artificial gravity already exists today. If the need develops, man will develop space colonization and train all types of personnel to support orbiting units. Extra-terrestrial basing and space stations will develop provided man has the need and can adapt to the environment.

Man in Space. As man needs room to develop and expand his universe, he will develop ways to inhabit the space environment. The need for man in space will have to develop to provide the push toward space habitation. This applies not only to colonization efforts but to man's presence in maintenance, deployment and control of space systems.

VII. Conclusions

Research Summary

The research reviewed past and current work relating space, space technology and the Air Force Civil Engineering policy for space. Many aspects of space were reviewed involving concepts of space maintenance. Interviews were held with key personnel to discuss concerns and efforts going on today. Finally, projections were made for work necessary for CE to prepare for future space operations. Projections included recommendations for action and research in various areas which should benefit Civil Engineering in the future.

It has been twenty years since man stepped on the moon in July 1969. In that time, man has made many significant advancements toward space. Skylab missions showed that man can exist and work in the space environment for extended periods of time. The space shuttle has provided a means for a launch and re-entry vehicle capable of successive uses. The Solar Max mission proved that retrieval of orbiting equipment is possible. Combining the results of Skylab, Solar Max and the shuttle, man's next step is a continued presence in space. Technology is developing to make that next step possible in a space station.

Air Force Civil Engineering has made a good start by establishing space policy and starting doctrine development. However, CE shows no evidence of short or long term plans. Plans are needed to provide a guide for research toward space. The emphasis at HQ AFSPACECOM is toward the short term. The plans office should focus on long term developments.

NASA leads the man in space issue. This is to the military's benefit. The unmanned missions best suit the needs of the military until manned military missions are identified. The focus for the military should be on support for ground facilities.

Air Force education and training for space is adequate for now. The Army has a well developed space education program. NASA provides the best simulation and training experiences. The Air Force could improve by providing continuing education courses in ground support complexes. Also, the Air Force should focus on improving support to ground facilities.

Man will eventually be in space. Unmanned programs are the mainstay for military needs today. However, man will strive to further explore space. Further exploration will lead to the need for man in space.

Technological advances will continue to benefit man on Earth. Several technologies can improve space operations. Developments in material processing will improve engineering capabilities. Construction materials, bonding agents and high-temperature resistant metals could improve the engineering field.

Maintenance procedures are the biggest shortfall for CE operations in space. Limited experience maintaining space facilities is the reason for a lack of knowledge in the area. Most of the work to prepare CE for a space mission must focus around developing maintenance procedures. Without a need for facility maintenance, CE may not have a role in outer space.

Technological improvements have improved life on Earth. Many of the advances common today were breakthroughs in technology geared toward space. Man's desire, either motivated by the exploration of space or the military use of space, will provide the technical push necessary to put habitable systems in space.

Although the colonization of space (or the moon) still seems very science-fiction, we are closer to the capability. The thought of man on the moon, at one time, was inconceivable. In the next twenty years, it may be a common event. Probably the greatest hinderance right now is the controversy over the need for man in space. The Earth still provides the natural resources man needs to survive. Until a need develops, space colonization will remain a part of science fiction.

Space continues to be a wide and growing field. As our knowledge of space and the number of space systems increase, the management of those systems become more complex. Civil Engineering must develop definitive plans now and continue to develop these plans in the future. From this initial start, the future of Civil Engineering in space will build on the foundations made today.

Recommendations for Further Study

Space is a broad category and encompasses many areas of research. Areas which require further investigation include:

1. Construction in space. Who will perform it? How will it be done? What materials will be required? What are the engineering requirements for construction in space?

2. The requirements for astronaut training and how they can be reduced for future personnel in space.

3. Further research on developing doctrine for Civil Engineering in the space operations area.

4. The possibility and requirements of a space training hangar which simulates the space environment.

5. Determination of feasible periodic and predictive maintenance intervals for various types of systems and scenarios.

6. Maintenance procedures for space facilities.

Appendix: Interview Questionnaire

Please provide as much information and data as possible. The interview will be recorded for future reference. Notes will be taken during the interview. However, if you would please write your answers so that any key terms or beneficial answers will be in your own words. I will attach a copy of the interview questions to my thesis.

POLICY - What is the guidance, if any, to conduct and prepare for space operations.

1) Do you know the present Air Force policy on space? If so, what is it?
2) Do you know the present Air Force Civil Engineering policy on space? If so, what is it?
   a) Express the policy in your own terms.
   b) How/when did the policy begin?
   c) Who started the policy/program and why?
3) What is the Civil Engineering role in space?
4) How will this role be carried out?
5) Who determines the responsibilities for space systems?

POLITICAL ISSUES - The political aspects of Civil Engineering as well as the Air Force in space.

1) What political issues are involved in Civil Engineering having a role in space?
2) Who will "control" space from an Air Force perspective? Who wants/does not want the responsibility/control of space facilities?
3) Are there any political battles to be fought? Who will decide who does what in space?
4) Does Civil Engineering need to be ready to fight/battle for space assets?
   If so, what type of battles and who will CE be fighting? What is being done to win those battles now? Does Civil Engineering need to be ready to not avoid responsibilities in space?

TRAINING & EDUCATION - A new mission requires a thorough understanding of the system by all personnel involved in its support. This is the function of training and education.

1) Is the Air Force providing training and/or education for personnel involved with the space mission? If not, when will a program be established?
2) What type of training is being conducted for persons responsible for the Civil Engineering role?
   a) Astronautical training?
   b) Training with the technology?

c) Maintenance of space systems? While on earth? While in outer space?

3) Is the Air Force developing training requirements and a training program to prepare for the Civil Engineering role in space?
   a) When did/will it begin?
   b) What are the educational requirements for personnel to be in space?
   c) Are there/will there be special requirements for the Civil Engineering personnel who go in space? What will these requirements be? How are these requirements established and by whom?
   d) Will the craftsmen of today (NCOs and airmen) be used in outer space?

4) Discuss the education programs which support the space role. Astronautical Engineering and Space Operations
   a) When did the program(s) begin?
   b) What is the purpose of these programs?
   c) How do these programs benefit the Air Force?
   d) How are the people with these educations used after they complete the program?
   e) Where do the graduates go? How are their educations used by the Air Force? How are these persons tracked?
   f) Does the Air Force use these persons now or are they "saved" for future reference? Some personnel are AFSC 55XX (Civil Engineers). How are these personnel used?
   g) How will the graduates be used in the future? What will their role be in space operations?

<u>TECHNOLOGY</u> - Space systems involve a differing technology associated with the atmospheric conditions and lack of gravity. Please address what is being done to work with the differing technology needed for space operations.

1) What technology is available today?
2) How does the technology to be used in space differ from technology used on earth?
3) How will this technological difference effect construction, maintenance, and repair of space systems?
4) How will Civil Engineering use the technology?
5) Is the Air Force (or Air Force Civil Engineering) working the area of new technology? If so, which agency and what are they doing? If not, where will the Air Force get the technology?
   a) Will we adopt the work of NASA?
   b) What is NASA doing?
   c) What connections/programs does the Air Force have with NASA?
   d) Is the Air Force or Air Force Civil Engineering working with NASA to train/educate personnel? Elaborate on the training/education these persons receive.

MAINTENANCE - The future of Civil Engineering involves space facilities which will require maintenance and repair.

1) How will maintenance and repair of space facilities be performed?
   a) What technology is involved?
   b) How will schedules be set?
   c) Will personnel responsible for maintenance and repair actions be stationed at space facilities?
2) Who will be the craftsmen to do the work?
   a) What will the education and training requirements be?
   b) Will engineering degrees be required?
   c) What special training will the craftsmen require?
3) What will be Civil Engineering's role in these maintenance and repair actions?
4) What distinguishes space facilities, space systems and space craft? Will there be any conflict with Naval ship number versus aircraft tail numbers versus space facility numbers?
5) Who determines the designation of a space system or facility?

OTHER COMMENTS, REFERENCES, NOTES

Please provide any further information, data, references, sources of material, etc... which you feel might be beneficial to my efforts. You may address any of the areas covered above or add any areas you believed need to be included. Feel free to add any comments, explanations, or other statements.

Bibliography

Air Force Space Technology Center. Space Systems and Technology Workshop II, Man-In-Space Panel Proceedings. Space Division Technical Report 83-015. Air Force Space Technology Center, Headquarters Space Division, Air Force Systems Command, United States Air Force, Los Angeles CA, October 1982 (AD-B071408).

Aldridge, Edward C. Jr. "Consistency: A Vital Ingredient for National Security Space Programs," Defense 88: 13-19 (November/December 1988).

Anzalone, Samuel L. Lyndon B. Johnson Space Center, Special Assistant to the Director, for USAF Space Command Liaison. Personnel interview. National Aeronautics and Space Administration office, Peterson AFB CO, 3 May 1989.

Bird, Julie. "AF aims to be main provider of space forces," Air Force Times, 49: 3 (24 April 1989).

Bowman, Major Richard L., II. "Space - The Logistics Challenge," Air Force Journal of Logistics, 10: 12-15 (Spring 1986).

Bratlien, Michael D. Chief, Civil Engineering Space Operations Branch, Headquarters, Air Force Space Command. Personnel interview. HQ AFSPACECOM/DEO, Peterson AFB CO, 2 May 1989.

Canan, James W. "Recovery in Space," Air Force Magazine, 71: 68-73 (August 1988).

Carlucci, Frank C. "DoD's Space Policy - An Overview," Defense 88: 2-6 (November/December 1988).

Classen, E. H. and R. H. Bentall. "Servicing Support Facilities," Space Technology, 8: 195-204 (January/February 1988).

Cushieri, Lieutenant Colonel Joseph M. The Role of the Army Corps of Engineers in Space, U. S. Army War College Study Project. U. S. Army War College, Carlisle Barracks PA, April 1986 (AD-B103844).

Department of Defense. Memorandum for Correspondents, Department of Defense Space Policy. Washington DC, 10 March 1987.

Department of the Air Force. Basic Aerospace Doctrine of the United States Air Force. AFM 1-1. Washington: HQ USAF, 16 March 1984.

Department of the Air Force. Military Space Doctrine. AFM 1-6. Washington: HQ USAF, 15 October 1982a.

Department of the Air Force. Resources and Work Force Management. AFR 85-1. Washington: HQ USAF, 21 May 1982b.

Disher, John H. "The Skylab Program - An Overview," Skylab and Pioneer Report, 36: 1-7. Tarzana CA, American Astronautical Society Publications Office, 1975.

Ellis, Major General George E., Director of Engineering and Services. Official Correspondence, Engineering and Services Space Support Policy. Headquarters United States Air Force, Washington DC, 2 December 1987.

Engineering and Services, Headquarters United States Air Force. Space Support Policy statement (signed by Major General George E. Ellis). Washington DC, undated.

Eubanks, R. A. and Alvin Smith. Investigation of Design Concepts for Large Space Structures to Support Military Applications, USA-CERL Technical Report M-87/16. U. S. Army Construction Engineering Research Laboratory, September 1987 (AD-A186098).

Fallstead, Captain Coral C. An Economic Feasibility Study on the Space-Based Production of Methane Gas from Human Waste through Anaerobic Digestion for Use as an Orbit Maintenance Propellant. MS Thesis, AFIT/GSO/ENS85D-8. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, December 1985.

Friedrich, H. and others. "Man-Tended Free Flyer Configurations and Servicing Scenarios," Space Technology, 8: 27-35 (January/February 1988).

Fuchs, Manfred. "From Satellites to the Space Station: The Trend Toward Larger Structures in Space," Proceedings of the International Business Strategy Conference on Space: The Commercial Opportunities. 103-111. London: Online Publications, 1984.

Gibson, Edward G. "Automation in Servicing of Customer Spacecraft and Platforms," Proceedings of the 32nd Annual American Astronautical Society International Conference. 95-97. San Diego: American Astronautical Society Publications Office, 1985.

Haise, F. W., Jr. " Servicing Satellites from the Shuttle," Grumman Aerospace Horizons, 18: 2-9 (1982).

Harper, Gene. "Space Soldiers," Soldiers, 42: 50-52 (January 1987).

Hartley, Craig. "Simulating Satellite Retrieval Missions Using the Manned Maneuvering Unit," Journal of Environmental Sciences, 28: 29-33 (March/April 1985).

Hathaway, R. G. W. "On-Orbit Servicing and Cost Effectiveness of Columbus Polar Platform Concepts," Proceedings of the International Geoscience and Remote Sensing Symposium, 1988. 191-194. Edinburgh U. K. ESA Publications Division, August 1988.

Headquarters United States Air Force. Memorandum for ALMAJCOM-SOA, Air Force Space Policy - INFORMATION MEMORANDUM. Washington DC, 2 December 1988.

Herres, General Robert T. "National Security and Our Role in Space," TIG Brief, 38: 2 (February 1986).

Herring, George E. "Product Support and Maintenance for Space-Based Systems," Logistics Spectrum, 22: 37-40 (Summer 1988).

Junge, Maria K. "Human Factors in Spacelab: Crew Training," Proceedings of the Human Factors Society - 27th Annual Meeting, 1: 552-556. Santa Monica CA, Human Factors Society, 1983.

Koser, Major Michael C. Uses of the US Space Station for Military Operations, ACSC Student Report 86-1440. Air Command and Staff College (AU), Maxwell AFB AL, April 1986 (AD-B101990).

Leigh, Dr. Gerald. Chief, New Mexico Engineering Research Institute/ Readiness Technical Analysis Group. Telephone interview. New Mexico Engineering Research Institute, Albuquerque NM, 9 May 1989.

Levy, Joel and others. " Servicing of User Payload Equipment in the Space Station Pressurized Environment," Proceedings of the 16th Intersociety Conference on Environmental Systems. 571-578. Warrendale PA: Society of Automotive Engineers Publication Division, 1986.

Lozar, Charles C. and L. D. Stephenson. State-of-the-Art Technologies for Construction in Space: a Review, USA-CERL Technical Report M-87/17. U. S. Army Construction Engineering Research Laboratory, September 1987 (AD-A188412).

Martin, Captain John. Civil Engineering Space Plans Branch, Headquarters Air Force Space Command. Personnel Interview. HQ AFSPACECOM/DEX, Peterson AFB CO, 1 May 1989.

National Aeronautics and Space Administration. Definition of Technology Development Missions for Early Space Station Satellite Servicing. Volume 1: Executive Summary Final Report. NASA Marshall Space Flight Center Contract NAS8-35042 with Martin Marietta Corporation. Marshall Space Flight Center AL, November 1984 (N85-12922).

O'Hara, John M. "Telerobotic Control of a Dextrous Manipulator using Master and Six-DOF Hand Controllers for Space Assembly and Servicing Tasks," Proceedings of the 31st Annual Meeting of the Human Factors Society, 2. 791-795. Santa Monica CA, Human Factors Society, 1987.

Ohkami, Yoshiaki and others. "An Enclosed Hangar Concept for Large Spacecraft Servicing at Space Station," Proceedings of the 15th International Symposium on Space Technology and Science. 1939-1944. Tokyo: AGNE Publishing, Inc., 1986.

Pabich, Captain Paul J. Developing a Voice-Controlled, Computer Generated Display to Assist Space Station Astronauts During Maintenance Activity. MS Thesis, AFIT/GSO/ENG/86D-1. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, December 1986.

Savage, George R. "The Challenge of Integrating Logistics in Support of the Shuttle," American Institute of Aeronautics and Astronautics/Society of Logistics Engineers 1st Space Logistics Symposium: A Collection of Technical Papers. 151-157. American Institute of Aeronautics and Astronautics, Inc., New York, March 1987.

Shevchenko, Vladislav. "What is Worth House Constructing?," Tekhnika-Molodezhi,Nr. 5: 22-26. FTD-ID(RS)T-0607-88, Translated by the Foreign Technology Division, Wright-Patterson AFB OH, September 1988 (AD-B125957).

Technology 2000: Report for the Director of Engineering and Services, Headquarters United States Air Force, Volume I: Combined Executive Summary. 1-28. New Mexico Engineering Research Institute/ Readiness Technical Analysis Group, Albuquerque NM, April 1988.

Uhlik, Lt Col Felix T. Chief, Civil Engineering Space Plans Branch, Headquarters Air Force Space Command. Personal interview. HQ AFSPACECOM/DEX, Peterson AFB CO, 1 May 1989.

Ulsamer, Edgar. "Strategic Connections in Space," Air Force Magazine, 70: 78-84 (August 1987).

White, G. C., Jr. "Apollo Quality through Predictive Testing," Proceedings of the Symposium on Testing for Prediction of Material Performance in Structures and Components. 253-267. Philadelphia: American Society for Testing and Materials, 1972.

The White House, Office of the Press Secretary. Fact sheet on National Space Policy. The White House, Washington DC, 11 February 1988.

Wilder, Captain Brendan L. Civil Engineering Space Operations Branch, Headquarters Air Force Space Command. Personal interview. HQ AFSPACECOM/DEO, Peterson AFB CO, 2 May 1989.

Wile, Captain David B. "Space Logistics Technology - The New Challenge," Air Force Journal of Logistics, 12: 30-34 (Summer 1988).

Winchell, David G. "Selecting Affordable Levels of Support from Spare Unit Suppliers for Hubble Space Telescope Orbital Maintenance," American Institute of Aeronautics and Astronautics/Society of Logistics Engineers 1st Space Logistics Symposium: A Collection of Technical Papers. 145-150. American Institute of Aeronautics and Astronautics, Inc., New York, March 1987.

Wyatt, Major Linda S. On-Orbit Space Maintenance, ACSC student report 87-2780. Air Command and Staff College (AU), Maxwell AFB AL, April 1987 (AD-B113130).

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Abstract

This research examines past and present work toward space operations for Air Force Civil Engineering. The objective is to determine work that is necessary for Civil Engineering to extend its mission into space. Topics discussed are policy, training, technology and maintenance concepts. Analysis of this information leads to projected actions Civil Engineering must take in the immediate and long range future.

We have learned many things from space research and development. Technological advancements from space research have improved our lifestyles. Training techniques developed to simulate space have been successful in duplicating the actual environment. Procedures for corrective and preventive maintenance of space systems was demonstrated on Skylab. The Solar Max mission proved that on-orbit retrieval is possible.

Civil Engineering has a policy statement for space support and is developing doctrine for space operations. Civil Engineering must develop doctrine and plans to implement space policy. Civil Engineering must develop a blueprint on how it will operationalize the concepts for space into actual procedures. An Office of Primary Responsibility should be organized for managing requirements, planning and developing the issues facing Air Force Civil Engineering. This office would also coordinate technical information about space.

New maintenance concepts and procedures are being developed and tested. The prominent maintenance methods are variations of aircraft maintenance. Present space assets are systems which do not use facilities maintenance. Civil Engineering must determine procedures for space facilities maintenance. On-orbit servicing is a logical extension for a future maintenance. The increasing capabilities of artificial intelligence will have a dramatic effect on maintenance procedures in space.

Other projections include power reliability for ground support facilities, training requirements for power technicians, improvements to training, proposed maintenance using on-orbit retrieval, terrestrial basing and man in space.